

Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

U. S. DEPARTMENT OF AGRICULTURE.

FARMERS' BULLETIN No. 277.

THE USE OF ALCOHOL AND GASOLINE IN FARM ENGINES.

BY

CHARLES EDWARD LUCKE, M. S., Ph. D.

*Assistant Professor of Mechanical Engineering,
Columbia University.*

AND

S. M. WOODWARD, M. S., M. A.

Irrigation Engineer, Office of Experiment Stations.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.

1907.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,

Washington, D. C., January 2, 1907.

SIR: I have the honor to transmit herewith and to recommend for publication as a Farmers' Bulletin of the Department a paper on the use of alcohol and gasoline in farm engines, based in part upon experiments carried out by C. E. Lucke, assistant professor of mechanical engineering, Columbia University, and S. M. Woodward, Irrigation engineer of this Office, under the direction of Elwood Mead, Chief of Irrigation and Drainage Investigations of the Office of Experiment Stations, under authority given the Office to investigate "the use of different kinds of power and appliances for irrigation and drainage."

The pumping of water for irrigation and drainage has already assumed great importance, as approximately 600,000 acres of land are irrigated with pumped water. A large part of the unreclaimed arid land can get water in no other way, and as a rule it is so located that fuel of any kind is difficult to get. Alcohol offers in such cases a hope of cheaper fuel, which may mean the reclamation of large areas, since the land irrigated can produce the fuel to maintain its water supply. At present it does not appear that alcohol will produce power as cheaply as gasoline where the latter can be easily obtained, but as a rule the regions where there will be the greatest demand for pumping are the farthest removed from sources of the common fuels, and, on the other hand, they can produce large quantities of crops from which alcohol can be made. This, with the improvements which will undoubtedly be made in alcohol engines, may bring alcohol into use as the distinctive fuel for pumping water for irrigation.

Owing to the fact that there are not on the American market any engines designed especially for alcohol, the experiments so far made have been with alcohol in the gasoline and kerosene engines familiar to the American market.

The purpose of these experiments is twofold: (1) To determine what can be done with alcohol in the existing engines, and (2) to learn what changes in the mechanism of the engines are necessary to secure the highest efficiency in the use of alcohol as a fuel. Since the removal of the tax on denatured alcohol this Office has been flooded with inquiries as to the possibilities of its use. In view of this it has seemed best to publish as a Farmers' Bulletin the essential facts brought out by the experiments made, with some popular matter on the use of gas engines for farm purposes, leaving the details and the more technical results of the tests to be published later, and such publication is therefore recommended.

Respectfully,

A. C. TRUE,
Director.

HON. JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

	Page.
Sources of power	5
Comparative cost of power from different sources	6
Comparative cost of energy in different fuels	7
Thermal efficiency	8
Adaptability of various types of engines	10
First use of alcohol engines	12
Elementary engine mechanism	15
Explosive mixtures	18
Limits of proportion	19
Temperature of ignition	19
Rate of propagation	20
Pressure due to explosion	22
Liquid fuels	22
Heat of combustion	25
Air necessary for combustion	26
Vaporization of fuel	27
Effect of initial compression	37
Practical experience with alcohol engines in Germany	37
Conclusions	39

ILLUSTRATIONS.

	Page.
FIG. 1. Diagram showing mechanism of internal combustion engine—suction stroke	16
2. Diagram showing mechanism of internal combustion engine—compression stroke	16
3. Diagram showing mechanism of internal combustion engine—expansion stroke	17
4. Diagram showing mechanism of internal combustion engine—exhaust stroke	17
5. Section of retort vaporizer	28
6. Section of retort vaporizer	28
7. Section of hot-bulb vaporizer	30
8. Section of Broubot vaporizer	31
9. Section of Daimler carbureter	33
10. Section of Maybach carbureter	33
11. Diagrammatic section of constant-level carbureter, with needle-valve adjustment	35
12. Diagrammatic section of constant-level carbureter, with overflow cup	35

THE USE OF ALCOHOL AND GASOLINE IN FARM ENGINES.

SOURCES OF POWER.

There are two great sources of power and an infinitely varied series of mechanical devices and machines for the generation of power. Water power always has been used and probably always will be used so long as the rain falls, but it is insufficient for our present needs or geographically unavailable. The greatest source of power is fuel. Fuels may be divided into two series—those that now exist in the form of natural deposits and those which are being produced continuously. All of the coals, hard and soft, with the lignites and peats, the crude oils and natural gas, exist in the form of deposits; and, while it is true that the decay of vegetable matter may be to-day forming more deposits of the same nature, it is equally true that we are using the present supply faster than the rate of production. The newest fuel for power purposes is alcohol. This is made from the yearly crops of plants. There is in existence no natural deposit of alcohol, but in a sense it may be said to be possible to produce inexhaustible supplies.

It is only within recent time that engineers have known how to build engines that would produce power from alcohol; and still more recent is the further discovery by engineers that this power can be produced at a cost which may permit its general introduction.

By far the largest part of the power now being used comes from steam produced by the use of coal. This is chiefly due to the fact that as a rule whenever it can be used it is cheaper than possible substitutes, although it is partly due to the fact that steam power is better adapted to some classes of work and is older and better known than power generated by the gas engine in its varied forms. In point of present use, water power stands next to steam in importance. This is largely due to the fact that water power is among the earliest in point of development, but more largely to the fact that it has become possible to transform water power into electrical power, which can be transmitted long distances, and so overcome geographical isolation of the sources.

Next in quantity produced stands power generated by the gas engine. This class of engines includes all machines in which the fuel mixed with air is burned or exploded within the working chambers, whether the fuel be gas produced from coal, natural gas, vapors of any of the mineral oils, vegetable or animal oils, or alcohol. The subordinate position occupied by this source of power is due partly to the fact that engineers have only recently discovered, and are to-day discovering, how best to build these machines and adapt them to the work they are to do. Wind and wave power stand at the foot of the list and always will, so far as quantity of power developed is concerned. This is because of the irregularity of the sources of supply and their comparatively feeble nature.

COMPARATIVE COST OF POWER FROM DIFFERENT SOURCES.

The cost of producing power from any of the above sources is made up of a number of items, including interest on the first cost of the installation, depreciation of the apparatus, its insurance, etc., usually called the "fixed charges." To these should be added the costs of fuel, of labor for attendance, and of repairs, as the principal items, and the cost of lubricants, material for cleaning, and a great many other small miscellaneous items, all going to form what are commonly called "operating charges." In all cases where fuel is used its cost is, if not the most important, certainly a very important item. In the case of water power, where the fuel element is zero, the advantage is offset by an interest charge on the cost of installation for dams, pipes, tunnels, shafts, etc. Assuming that power from all of these different sources is equally well adapted to the particular work to be done and equally available, then that system will be selected for any particular case for which the cost of power is least. Leaving out of consideration water power, it is found that the labor costs do not differ nearly so widely for the different systems, nor are they so large, as the fuel cost. Therefore, the great question to-day in power production as regards immediate cost of power and maintenance is this lowering of the fuel cost.

The cost of fuel per unit of power developed depends, first, on the market price of that fuel at the point where it is to be used, and next, but by no means least, on the ability of the machinery to transform the fuel energy into useful work. If all the different kinds of machinery used for power generation could turn into useful work the same proportion of the energy in the fuel, coal would be almost universally used, because of the present low cost of energy in this form.

COMPARATIVE COST OF ENERGY IN DIFFERENT FUELS.

The different kinds of fuel contain different amounts of energy per pound—that is to say, they have different heating powers. Heat energy is measured in terms of a technical unit called by English-speaking people the “British thermal unit” (B. T. U.). This unit is the amount of heat that will raise the temperature of 1 pound of water 1 degree on the Fahrenheit thermometer. In comparing, therefore, the value of fuels for power purposes there must be taken into consideration two facts—the market price of the fuel and the amount of heat which will be liberated when it is burned. Anthracite coal in the neighborhood of New York can be bought in small sizes in large quantities for power purposes at about \$2.50 per ton. This coal will contain about 12,500 B. T. U. per pound. This is equivalent to about 10,000,000 heat units per dollar. Large sizes, such as egg coal, containing about 14,000 B. T. U. per pound, can be bought in large quantities for about \$6.25 per ton, which is equivalent to 4,500,000 B. T. U. per dollar. Other grades of anthracite coal and the various grades and qualities of bituminous coal will lie between these two limits of cost. Illuminating gas in New York costs \$1 per 1,000 cubic feet, which is equivalent to about 500,000 heat units per dollar. Natural gas in the Middle States is sold for 10 cents per 1,000 cubic feet and upward. This fuel at the minimum price will furnish about 10,000,000 heat units for a dollar. Crude oil sells in the East at a minimum price of 4 cents per gallon, which is equivalent to about 4,000,000 heat units per dollar. Gasoline sells at a minimum price of 10 cents per gallon, which is equivalent to about 1,200,000 heat units per dollar. Kerosene sells from 10 to 30 cents per gallon, which is equivalent to 1,200,000 and 400,000 heat units per dollar, respectively. Grain alcohol, such as will be freed from tax under the recent legislation, will sell for an unknown price; but for the purpose of comparison, assuming 30 cents per gallon as a minimum, it will give 270,000 heat units per dollar. Gasoline, kerosene, crude oils, and, in fact, all of the distillates have about the same amount of heat per pound; therefore, at the same price per gallon, ignoring the slight difference in density, they would deliver to the consumer about the same amount of heat per dollar, whereas the other liquid fuel, alcohol, if sold at an equal price, would give the consumer only about three-fifths the amount of heat for the same money. From the figures above given it appears that the cost of heat energy contained in the above fuels, at the fair market prices given, varies widely, lying between 200,000 heat units per dollar and 10,000,000 heat units per dollar. It is possible to buy eight times as much energy for a given amount of money in the form of cheap coal as in the form of low-priced gasoline, or twenty-

five times as much as in the form of high-priced gasoline or kerosene. This being true, it might seem to a casual observer as rather strange that gasoline should be used at all, and the fact that it is used in competition with fuel of one-eighth to one twenty-fifth its cost shows clearly that either the gasoline engine has some characteristics not possessed by an engine or plant using coal, which makes it able to do things the other can not do, or that more of the heat it contains can be transformed into energy for useful work. Both of these things are true.

THERMAL EFFICIENCY.

As was pointed out before, the different kinds of machinery used to generate power render more or less of the fuel energy into useful work; all systems do not give equal returns for equal amounts of heat supplied. If all the heat energy in fuel were transformed into work with no losses whatever in the mechanism, the machinery would be said to have a thermal efficiency of 100 per cent, and it would require 2,545 heat units per hour to maintain an output of 1 horsepower. If half of the energy in the fuel were lost in the machinery, its thermal efficiency would be said to be 50 per cent, and there would be required 5,090 heat units per hour. If only 1 per cent of the heat energy in the fuel were transformed into useful work, the efficiency of the machinery or power plant would be said to be 1 per cent, and there would be required 254,500 heat units per hour to maintain 1 horsepower.

Steam plants in use represent a great variety of styles or types, but in general it may be said that the more complicated and refined the plant and the larger its size the more efficient it is, because the complication exists only as evidence of an attempt to minimize the losses of heat in the machinery. Similarly the more steadily the plant works at the output for which it was designed the higher the efficiency of the plant, and conversely, the smaller the plant, the simpler the apparatus, or the more intermittently it works, the lower its efficiency. Steam-power plants are built to-day to do every conceivable sort of work, and range in size from 1 horsepower to 100,000 horsepower. For purposes of comparison neither the largest nor the smallest should be used, nor the best performance nor the worst performance of these plants, but a figure representing a fair average for the conditions named should be taken. Large steam plants in their daily work seldom use less than 2 pounds of poor coal per hour for each useful horsepower (known as a brake horsepower), which is equivalent to about 25,000 B. T. U. per hour, and which corresponds to about 10 per cent thermal efficiency. Small steam plants working intermittently, such as hoisting engines, may use as high as

7 pounds of coal per brake horsepower, which is equivalent to about 100,000 heat units per brake horsepower hour, or 2.5 per cent thermal efficiency. Some plants will do better than the above with proper conditions, and some may do worse, but in general it may be said that the performances of steam plants lie between the limits of 2.5 and 10 per cent thermal efficiency.

Plants consisting of gas producers for transforming coal into gas for use in gas engines have in general a much higher thermal efficiency than steam plants doing the same work. They are, however, not built quite so small as steam plants, the smallest being about 25 horsepower, and in general they have not been built so large, the largest being only a few thousand horsepower. Their efficiency, however, does not vary so much as is the case with steam plants. It may be fair to say that under the same conditions as above outlined these plants will use 1½ to 2 pounds of coal of fair or poor quality per brake horsepower hour, which gives a thermal efficiency ranging from 18 to 10 per cent. These plants can be made to do much better than this, and perhaps may do worse, although the variation is not nearly so great as for steam plants.

Gas engines operating on natural gas or on illuminating gas from city mains will, on fluctuation of load with the regular work, average about 12,000 heat units per brake horsepower hour, or 20 per cent thermal efficiency. Exploding engines operating on crude oil will average about 25,000 heat units per brake horsepower hour, which is equivalent to about 10 per cent thermal efficiency. Exploding engines using gasoline should operate at a thermal efficiency of about 19 per cent under similar operating conditions.

The efficiency of an alcohol engine may be assumed at this time to be unknown, but as alcohol can be burned in engines designed for gasoline, it may be assumed that such an engine will have with alcohol fuel the same thermal efficiency as with gasoline, to wit, 19 per cent for fair working conditions.

From the above brief discussion of the efficiency of different methods of power generation from different fuels it appears that quite a range is possible, though not so great a range as exists in the case of cost of fuel energy. Efficiency is seen to lie somewhere between 2½ and 20 per cent for all the fuels under working conditions. It is known that actual thermal efficiency under bad conditions may be less than 1 per cent and under the best conditions as high as 40 per cent, but these are rare and unusual cases. The range given is sufficient to indicate that a highly efficient method may make the fuel cost per unit of power less with quite expensive fuel than it would be with cheaper fuel used in a less efficient machine. It is also perfectly clear that without proper information on the efficiency of the

machine or the efficiency of the plant it is impossible to tell what the cost of fuel per horsepower hour will be, even though the price of the fuel per ton or per gallon be known. From the figures given on the cost of fuel and a fair average for plant efficiency the cost of fuel per horsepower hour is computed as given in the following tables:

Cost of energy in fuels.

Kind of fuel.	Cost of fuel.	British thermal units (B. T. U.).	Number of B. T. U. bought for \$1.
Small anthracite	\$2.50 per ton	12,500 per pound	10,000,000
Large anthracite	6.25 per ton	14,000 per pound	4,500,000
Illuminating gas	1.00 per 1,000 cubic feet	550 per cubic foot	550,000
Natural gas . . . . .	.10 per 1,000 cubic feet	1,000 per cubic foot	10,000,000
Crude oil . . . . .	.04 per gallon	20,000 per pound	3,650,000
Kerosene . . . . .	.10 per gallon	20,000 per pound	1,200,000
Do . . . . .	.30 per gallon	20,000 per pound	400,000
Gasoline . . . . .	.10 per gallon	20,000 per pound	1,200,000
Do . . . . .	.30 per gallon	20,000 per pound	400,000
Grain alcohol . . . . .	.30 per gallon	12,000 per pound	270,000
Do . . . . .	.40 per gallon	12,000 per pound	200,000

Fuel cost of power.

Fuel and type of plant.	Fuel required per horsepower per hour.	British thermal units re- quired per horsepower hour.	Thermal efficien- cy.	Cost of fuel.	Cost of fuel per horse- power per hour.
			Per cent.		Cents.
Anthracite coal:					
Large steam plant	2 pounds	25,000	10	\$2.50 per ton . . . . .	.25
Do	2 pounds	25,000	10	6.25 per ton . . . . .	.57
Small steam plant	7 pounds	100,000	24	2.50 per ton	1.00
Do	7 pounds	100,000	2½	6.25 per ton	2.20
Producer gas plant	1½ pounds	14,000	18	2.50 per ton . . . . .	.14
Do	1½ pounds	14,000	18	6.25 per ton . . . . .	.31
Do	2 pounds	25,000	10	2.50 per ton . . . . .	.25
Do	2 pounds	25,000	10	6.25 per ton . . . . .	.57
Illuminating gas	24 cubic feet	12,000	20	1.00 per 1,000 cubic feet . . . . .	.20
Crude oil	1.4 pints	25,000	10	.04 per gallon . . . . .	.68
Gasoline	1.1 pints	13,400	19	.15 per gallon	1.70
Do	1.1 pints	13,400	19	.30 per gallon	3.40
Alcohol	—	—	“ 19	.30 per gallon	5.00
Do	—	—	“ 19	.40 per gallon	6.70

* Efficiency of alcohol is assumed to be the same as that of gasoline for identical conditions of use.

ADAPTABILITY OF VARIOUS TYPES OF ENGINES.

The foregoing table shows very clearly that the cost for fuel to maintain a brake horsepower for one hour varies widely, and at the prices given the dearest costs nearly 48 times as much as the cheapest. The fact that not everybody uses the fuel giving the cheapest power in point of fuel cost, but that even the most expensive finds a ready market, makes it clear that there must be good reasons. These reasons may be found in local variations in price of fuel, in differences in adaptability of the engines to the work required, and in the fact that the above figures show fuel cost only, whereas there are great differences in the cost of attendance. An elaborate steam plant, to be even fairly efficient, must be continuously operated at

fairly heavy load; intermittent working or working at a decreased output makes them wasteful of fuel. Moreover, the apparatus is so complicated, slow to start up, and dangerous to life and property in careless or inexperienced hands that persons must become skilled by years of study and practice before they may be allowed the handling.

The gas engine with its producer can handle to-day the same kind of coal that is used in steam plants, and yet the weight of this apparatus and its lack of flexibility, compared with steam engines, make it unavailable for steamships and locomotives; so it is clear again that adaptability to service is even more important than the cost of fuel. Similarly, gas-producer plants have not yet been successful for sizes smaller than 25 horsepower, and especially unsuccessful have they been so far for intermittent work. For the small sizes the steam plant is also very wasteful of fuel, requires a skilled operator, and is slow in starting; so it is clear why engines burning crude oil, gasoline, kerosene, and other liquid fuels explosively should be used for light work in isolated situations where the work is intermittent and where quick starting and small care in attendance are essential. In this connection it must not be forgotten that a kerosene, gasoline, or crude-oil engine can be started in a few minutes and can even be left running for practically a whole day with only an occasional examination to see that the oil cups are flowing properly and the bearings are not getting hot through being dirty. Steam engines with their boilers, on the contrary, can not be started inside of one or two hours, and all the fuel necessary to raise steam is wasted so far as the work to be done is concerned. Moreover, a steam engine requires continuous feeding of coal and close attention, so that a man must be always near it, having no other duties but its care.

In the natural-gas regions a large number of gas engines are working and in the oil regions a similar number of oil engines and gasoline engines, because the nearness to the supply makes the fuel cheaper than transported fuel, and the exploding engine is more efficient than the steam engine.

It thus appears that in spite of the fact that the fuel element in the cost of power is high for engines burning crude oil, kerosene, and gasoline in comparison with those using coal, at the same time they possess advantages that do not exist in steam plants and gas-producer plants, which give them a very distinct field, as indicated by the following uses to which these engines are being put to-day: Driving boats, automobiles, and railroad motor cars; pumping water for private houses, for farms, for irrigation, and in some cases for municipal service in small towns; compressing air for drilling, hoisting, riveting, etc.; operating small carpenter shops, machine shops, forge shops, and, in fact, any kind of small shop; operating ventilating fans in buildings and in mines; running small factories, such

as creameries and butter factories; operating feed-cutting and grinding machinery, corn shredders, and thrashing machines; operating other special machines, such as ice-cream freezers, printing presses, mostly small in size, and making electric light in isolated localities. Not only is this field a real one, but it is a large one, as is shown by the number of these small engines being sold to-day. The exact figures on the sales are not available and it is impossible to secure them because of the unwillingness of manufacturers to tell their business; but when a single manufacturer (as is the case) is selling 425 per day, and there are in the United States alone some 300 manufacturers of importance, there can be no doubt as to the popularity of these machines.

Alcohol at a price unknown now becomes available for use in engines, whose peculiarities are not fully known and whose ability to transform heat into work is correspondingly in question. If the alcohol engine can be shown to have an efficiency as high or higher than other liquid-fuel engines and be similar in type and characteristics, it can do all that they can do, and its field will be the same as their field in spite of fuel costs; but by field is meant the nature of the work rather than the geographical location. It is likely that the alcohol engine will find as favorable a geographical location as the natural-gas engine and the oil engine have near the source of supply and far from the source of competing supply. But should it appear that the alcohol engine can do more or better work than its oil or gasoline competitors, its field will be wider. In any case the position which the alcohol engine may take to-day is no criterion as to its future, because it will operate on a source of energy or fuel supply which, as pointed out, is inexhaustible, whereas the supply of both crude oil and its distillates may ultimately become exhausted.

The determination, then, of the position of the alcohol engine to-day involves a forecast of the future, and should it be shown to be able to compete now it must inevitably reach a stronger and more important industrial position as time goes on. This is the fact that has led governments to take up the question, and among them the United States is the latest.

FIRST USE OF ALCOHOL ENGINES.

About the year 1876 there was placed on the American market the first successful internal-combustion engine using petroleum distillate. This engine was invented by George Brayton. Following the attempt of Brayton to use petroleum distillate came a series of inventions improving this class of engine, lasting for about twenty years, when the modern forms of kerosene, gasoline, and crude-oil engines may be said to have been developed. During this time the subject of alcohol as fuel in engines seems to have been either not

thought of at all or not given any attention. The first serious attempt to examine into the possibility of alcohol as a fuel in competition with petroleum and its distillates seems to have been made in the year 1894 in Leipzig, Germany, by Professor Hartman for the Deutschen Landwirtschafts-Gesellschaft. The engine used was built by Grobb, of Leipzig, to operate on kerosene, and used 425 grams of kerosene per hour per brake horsepower, which is equivalent to 0.935 pound, or 1.1 pints, approximately. This indicates for the kerosene a thermal efficiency of 13.6 per cent. When operating on alcohol the engine used about twice as much, or 839 grams, which with this kind of alcohol was equivalent to a thermal efficiency of 12.2 per cent, or a little less than with kerosene. This experiment would seem to indicate that, compared with kerosene, alcohol, as a fuel, offered very little chance for successful competition. In spite of this, however, very vigorous efforts were made to develop an alcohol engine that would be better than this one, and thus was inaugurated a remarkable series of experiments, congresses, and exhibitions with the one end in view—of stimulating the production of the best possible alcohol motor.

The first stimulus was given by the German alcohol distillers, who sought to enlarge their market. They succeeded in interesting the German Government in the question by enlarging on the national significance of having available a source of fuel for power, inexhaustible in quantity, to be produced within the national domain from the yearly crops. Under the double stimulus of government assistance and the desire of the distillers to increase their output, inventors and manufacturers were induced to spend their time and money with a resulting decided improvement in the motor. An engine built by Körting Brothers, of Hanover, fitted with a vaporizer invented by Petreano; tested at the Polytechnic School at Charlottenburg by Professor Slaby showed a consumption of 550 grams of 86.2 per cent alcohol by weight, which is equivalent to 1.21 pounds, or 1.4 pints, or a thermal efficiency of 17.5 per cent. This result showed an advance of nearly 50 per cent in thermal efficiency over the Grobb engine tested a year or so earlier by Professor Hartmann. Following this improvement there resulted a continual development of the alcohol motor, interest in which was kept up by exhibitions in which prizes were offered and by scientific societies. The most important of these are given below.

- Exhibition at Halle-on-Saai, Germany, June 13-18, 1901.
- Exhibition (national) at Paris, France, November 16-24, 1901.
- Exhibition at Berlin, Germany, February 8-16, 1902.
- Exhibition (international) at Paris, France, May 24-June 1, 1902.
- Exhibition at Madrid, Spain, late in the year 1902.
- Congress at Montpellier, October 11-21, 1902.
- Congress at Paris, France, March 11-17, 1902.
- Exhibition (international) at Vienna, Austria, April 2-June 12, 1904.
- Exhibition at Rome, Italy, February 6-16, 1904.

Besides the above named, there were many others of lesser importance, all contributing to the rapid development of this class of machine.

The results of this development may be summed up by saying that the thermal efficiency of the motor was raised to something over 30 per cent, which is quite a remarkable showing in comparison with the original figure of 12.2 per cent in 1894. It must be clearly understood, however, in interpreting these figures that they are the best possible attainable at the time reported. They indicate, so far as the fuel costs are concerned, that with a motor specially constructed for alcohol the fuel prices per gallon might be twice as much for alcohol as for petroleum distillate and still give power for less money, assuming that attendance, repairs, lubrication, etc., cost no more in the case of the alcohol engine.

The Office of Experiment Stations of this Department, in connection with its Irrigation and Drainage Investigations, has tested a number of different types of gasoline engines with alcohol and obtained figures which show the comparative consumption of gasoline and alcohol in the same engine. The detailed results of these tests will be published in a technical bulletin, but the general results may be given here. The first tests were made without any particular attempt at obtaining the best adjustment of the engine for each fuel, and showed a consumption of alcohol two to three times as great by weight per horsepower hour as was necessary with gasoline or kerosene. These figures indicate the necessity or desirability of determining the proper conditions of adjustment, because these were found to have a serious influence on the amount of fuel consumed. With care in adjusting the engine so as to secure the most economical use of the alcohol, it was found that, under like conditions, a small engine consumed 1.23 pounds of alcohol to 0.69 pound of gasoline per brake horsepower hour—that is to say, with the best adjustment of the engine for each fuel there was required 1.8 times as much alcohol by weight as gasoline per brake horsepower hour. It was also shown in making this adjustment that it was possible to burn more than twice as much alcohol as stated, by improper adjustments, and still have the engine working in an apparently satisfactory way. The range of excess gasoline which might be burned without interfering seriously with the working of the engine was not so great, being a little less than twice as much as the minimum. These early experiments, therefore, confirmed the early results secured in Germany, to wit, that an engine built for gasoline or kerosene will, when unchanged, require about twice as much alcohol by weight for the same work; but they also indicate something that is not pointed out by the

reports sent us from abroad—that is, the great importance of securing the best adjustment of the machine.

To understand why this adjustment of the machine can have such a serious effect and at the same time understand why exploitation and study were successful abroad in raising the efficiency of the alcohol engine from 12.2 to over 30 per cent in five or six years requires a knowledge of technology. The reasons can only become clear to one understanding the mechanism of these engines and to one familiar with the chemistry of the fuels and the physical theories of explosive combustion.

ELEMENTARY ENGINE MECHANISM.

Every exploding engine operating with crude oil or its distillates, or alcohol, must have certain parts, no matter how different engines may vary in other details. These parts are a cylinder in which a sliding plug or piston works back and forth, carrying a pin called the wrist pin, to which is fastened a connecting rod, the other end of which fits in another pin called a crank pin. This crank pin is at one end of an arm called the crank, on the other end of which is the shaft or crank shaft. The piston moves back and forth in the cylinder, but when nearest the cylinder head there is still some space left between the walls, valves, and the piston head. This space is called the clearance, or the explosion chamber, and is the space in which the charge is compressed before it is exploded. In the clearance walls or cylinder head there are two valves in the form of disks, which cover the openings or ports. Through one of the valves an explosive mixture, having certain characteristics to be explained later, is admitted from the source of fuel supply and from the air. Through the other valve the products of combustion after an explosion are expelled. Their duty gives these valves the names of inlet and exhaust valves, respectively. Four strokes are usually required to complete the cycle of events occurring within the cylinder, and to engines requiring these four strokes the name four-stroke cycle or four cycle is given. There are certain other engines with different valve arrangements, which may complete a series of operations in two strokes and these are called two-cycle engines.

• The series of operations requiring four strokes is best illustrated by a set of diagrams. In figures 1 to 4 is shown a cylinder with the parts connected to it. On the first stroke or on stroke (fig. 1) the piston is drawn forward either by hand when starting or by the action of fly wheels after the engine is put in motion. This moving forward of the piston is accompanied by an opening of the inlet valve, permitting the explosive mixture to follow the piston and fill the cylinder. The clearance space, before this suction stroke begins,

is filled with burnt gases from the previous explosion, so that the amount of mixture drawn in will be equal to the volume displaced by the piston, and this fresh mixture will be mixed with some burnt gases. At the end of suction the inlet valve is closed and compression begins (fig. 2), continuing through the second stroke. During this process both valves are closed and the fresh charge, together with the residue of burnt gases, is squeezed into the clearance space so that it will have as a result a considerable pressure, called the compression pressure, preparatory to exploding. At the end of compression an electric spark explodes the charge, causing the pressure to rise two to four and one-half times the compression pressure. This high pressure in the clearance space will then drive the piston forward.

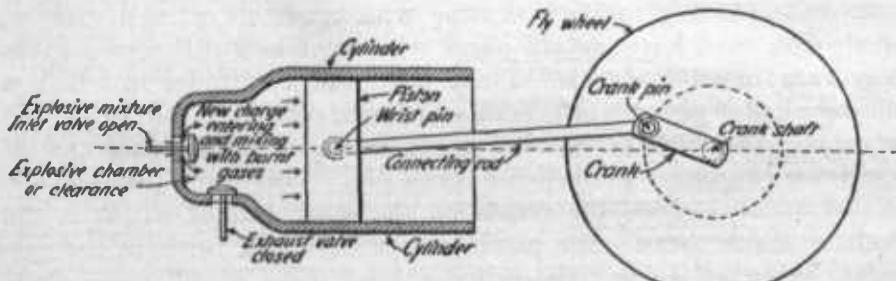


FIG. 1.—Diagram showing mechanism of internal combustion engine—suction stroke.

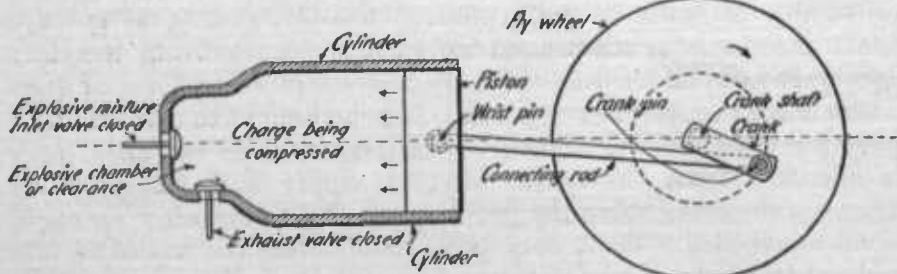


FIG. 2.—Diagram showing mechanism of internal combustion engine—compression stroke.

This stroke, the third or outstroke (fig. 3), is accomplished by the high pressure of the gases filling the explosion chamber and during the progress of the piston the pressure gradually falls, as expansion takes place. During this time both valves are closed, as during the compression. At the end of the expansion (fig. 4) the exhaust valve opens and the piston returns under the influence of the fly wheel, which has been spun around by the explosion, giving the fourth stroke or instroke. The exhaust valve being open for this stroke, most of the burnt gases are expelled, but some are retained in the clearance. After this the fifth stroke begins, which is the same as the first stroke, and subsequently the whole series repeats itself indefinitely and automatically.

While the above operations are usual and the above parts are likewise important, an engine having no more mechanism than is shown would not run. There will be required in addition to what is shown a valve gear, which is a mechanism for opening and closing the valves at the proper time. There must be also some device for making a mixture having the proper characteristics for explosion. This mixture will consist of air and the vapor of the liquid fuel, so that there must be supplied a carburetor, which vaporizes and mixes at the same time, or a vaporizer which vaporizes without mixing. There must also be a mechanism for automatically producing an electric spark at the proper time. This constitutes an igniting gear. The explosions will heat the cylinder so much that a lubricating oil

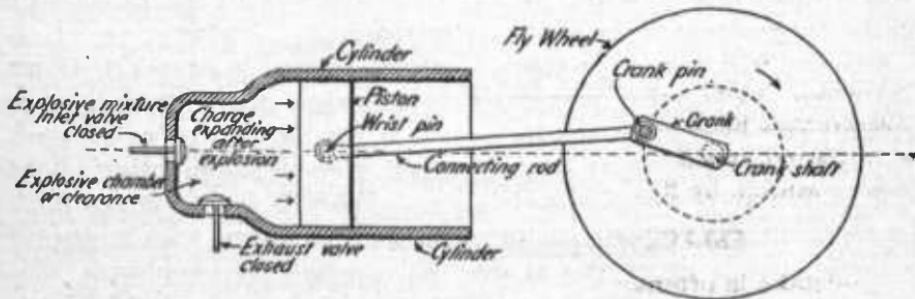


FIG. 3.—Diagram showing mechanism of internal combustion engine—expansion stroke.

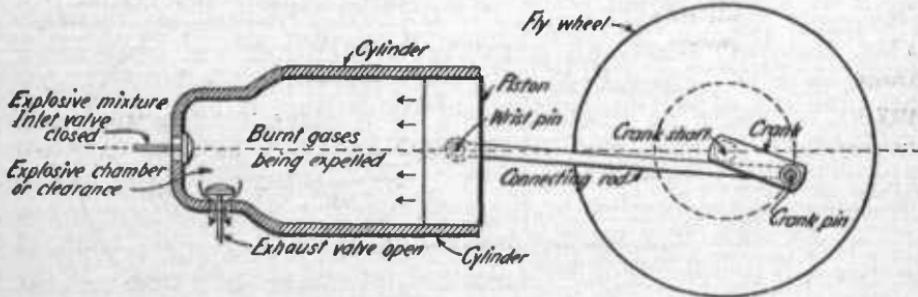


FIG. 4.—Diagram showing mechanism of internal combustion engine—exhaust stroke.

will burn and the piston stick; therefore some cooling device must be supplied, generally in the form of a jacket surrounding the whole cylinder and containing water. If the engine is to do stationary work it must operate at a constant or nearly constant speed, regardless of the amount of work done. This requires a governor. The explosions are very loud; therefore such engines are equipped with a "muffler" to lessen the noise. The rubbing parts, viz., the piston, the main bearings, and the crank shaft, wrist pin, crank pin, valve gear, igniting gear, governor, etc., must all be lubricated to prevent overheating and undue wear, so that a lubrication system is required.

Different makes of engines differ in the above details. All have some provision for performing what is pointed out as necessary, and

it is here that inventors and engineers exhibit their skill. All of these engines work as a result of the combustion of the explosive mixture of vapor and air, and a proper understanding of how the various styles of mechanism or changes in detail may affect the engine, requires a preliminary knowledge of their effect upon the explosive mixture.

EXPLOSIVE MIXTURES.

It is easy to understand how an engine may operate without understanding the well-known facts concerning explosive mixtures; but it is impossible to comprehend why engines should differ in fuel consumption or horsepower, good regulation, or any other characteristic without first studying in detail the influence of the mechanism on the composition of the explosive mixture.

Any fuel will burn when there is oxygen present in proper quantity and when the fuel has previously been heated sufficiently. This is true for any kind of combustion, such as the burning of wood, coal, oil in a lamp or cook stove, or gas issuing from an illuminating jet, as well as mixtures in exploding engines. When a fuel is mixed with air containing the right amount of oxygen, or mixed with any solid or liquid containing oxygen in the right amount, then explosive combustion is possible. If such a mixture be ignited at one point by heating it by a flame, a hot plate, or an electric spark, the combustion will travel through the entire mass of its own accord. Otherwise stated, the combustion will be self-propagating. When a mixture has this property of self-propagation of combustion it may be said to be explosive, whether the propagation be fast or slow or whether the explosion be accompanied by noise or not. Gunpowder consists of fuel in the form of carbon or charcoal, together with a little sulphur and a salt, such as a nitrate, containing oxygen. A long train of powder will completely inflame itself if lighted at one point. If the powder be of good quality and pure, the flame will propagate very rapidly. If, however, the powder have some sand or dirt mixed with it, the flame may still propagate, but more slowly, and finally, if there is too much dirt or inactive material present, it will be impossible to ignite the whole mass by self-propagation. Engine mixtures do not consist of solid fuel like gunpowder with oxygen in the nitrate form, but on the contrary consist always of gaseous fuel or liquid fuel vapor mixed with air. The combustion of gaseous mixtures is very much the same in nature as the combustion of gunpowder, which is not thought of as a mixture but which really is. If a mass of explosive mixture be contained in a vessel or in a glass tube and be ignited at one end of the tube, the eye can distinctly follow a flame traveling through the tube. The entire tube does not show a flame at any one time, but instead it will be found that the

flame is in the form of a disc or cap and that this flame cap travels through the tube, the flame cap being blue in color, with slight variations. When it has traveled past a certain point all the mixture between that point and the place where the combustion started is burnt, and all the mixture beyond the flame cap is still unburned.

LIMITS OF PROPORTION.

When the air and vapor are mixed in just the proportion known to be chemically correct the mixture is explosive. If it contains a small excess of fuel—that is to say, a little more fuel than the air present will burn—it may still be explosive, but much excess of fuel will cause it to cease being explosive. There is thus a high limit to the explosive proportions. Similarly, if there is present a little more air than is necessary to burn the vapor, the mixture will be explosive, but much excess of air will make it nonexplosive; and therefore there is a low limit to the proportions for explosive combustion. Mixtures of all proportions between the high and low limits will burn explosively. If to any explosive mixture there is added some inactive gas, such as nitrogen, carbonic-acid gas, steam, or the products of combustion of a previous explosion, the mixture will not burn so well as without this neutral addition. If there is much neutral added, it will be found that the mixture is no longer explosive, although the proportions of air to vapor are quite right chemically. Thus there is a third limit by neutral dilution. Therefore, for a mixture to be explosive it must contain air and vapor, though not too much air, gas, or neutral. A mixture which by reason of its proportions is beyond the range of explosive combustion may be rendered explosive by compressing it without in any way changing the proportions of air to gas or the amount of neutral present, and the more it is compressed the more rapid will this self-propagated combustion be. Temperature has a similar effect on the limiting proportions.

TEMPERATURE OF IGNITION.

By careful experimenting in scientific laboratories it has been found that explosive mixtures of different fuels do not all ignite at the same temperature; that some, for instance, must be heated to a higher temperature than others to start combustion. It has been found also that the temperature of ignition is lower for any given fuel when there is just a little excess of fuel in the mixture. If the mixture contain much excess of fuel, it must be heated to a higher temperature before ignition can be started. The temperature of ignition for any mixture will not be raised by adding inactive gas or by changing properties, but it may take a longer time to ignite when weak.

It has been found that raising the pressure or raising the temperature of the mass before attempting to ignite it will cause it to apparently ignite more easily. The time necessary to start ignition is lessened if the mixture be confined so that it can not circulate. It appears that a mass of mixture being heated at one point in an attempt to ignite it acts very much like the air in a room when the room contains a radiator for heating. The mixture near the radiator rises before becoming very hot, and it takes some time before any part of the mixture can be raised to the temperature sufficient to ignite it unless the circulation be suppressed. While no exact figures are available for the temperature of ignition for the mixtures used in these exploding liquid fuel engines, they can be placed in the following order:

Kerosene mixtures have the lowest temperature of ignition.

Gasoline comes next but is quite close to kerosene.

Alcohol mixtures have the highest temperature of ignition and are quite far removed from kerosene and gasoline.

RATE OF PROPAGATION.

The velocity with which the flame cap travels through the mass of mixture is termed the "rate of propagation," and this is sometimes very high and sometimes very low. Mixtures containing a certain small excess of fuel over what seems to be chemically correct burn faster than any other mixtures of that fuel. With much excess of fuel, much excess of air, or much neutral gas, the rate of propagation becomes lower, so that mixtures burn slower the further they depart from the proper chemical proportions (with the exception noted) or the more inactive or neutral gas they contain. The nature of the fuel has an influence on the rate of propagation and for our purpose it is only necessary to cite kerosene, gasoline, and alcohol mixtures. Kerosene mixtures burn fastest, and so have the higher rate of propagation. Next come gasoline mixtures and lastly alcohol, with the lowest rate of propagation, assuming, of course, always the correct mixtures in each case. The higher the pressure of the mixture before ignition the faster it will burn, so that the rate of propagation depends upon the pressure. Similarly, the hotter the mixture when ignited the faster it will burn, so that increase of temperature makes it burn faster or raises the rate of propagation. The shape of the chamber containing the mixture has a very decided effect on the rate of propagation. It was found by observing mixtures burning in glass tubes that, when very small tubes were used, the rate of propagation became perceptibly retarded, and when extremely small tubes were used the rate of propagation was zero; that is to say, the tube can be made so small that the flame will not propagate itself through the tube at all. This is because with very small tubes the heat can be

conducted away from the flame faster than the flame liberates it, with the effect that combustion ceases simply by cooling, just as water quenches a fire. If, in a tube so small as to prevent propagation, the mixture be compressed, it will liberate heat faster by reason of its greater density, and self-propagation will then be possible. It appears, then, that affecting this rate of propagation there is a whole series of influences, some tending to make it less, others more, with the consequent result of making it difficult to predict what will happen in a new case. A knowledge, however, of these causes of increase and decrease is essential in the interpretation of engine results, because the rate at which pressure rises in the cylinder after explosion depends upon the relation between the rate of propagation in the mixture and the piston speed of the engine. The motion of the piston outward tends to lower the pressure, while combustion by self-propagation tends to raise it. If the piston speed be small in proportion to the rate of propagation the pressure will rise in the cylinder rapidly. If, however, the piston speed be great and the rate of propagation small, the pressure may not rise at all in the cylinder or it may even fall during the explosion.

Aside from the mere question of average velocity of propagation, there is another question of great importance, and that is the mode of propagation. It has been shown by the work of the French scientists that there are three modes of propagation, or that the wave cap travels through the mass in three ways, each producing different effects and all of them influencing the performance of an engine. If the mass be free to expand while burning, the flame will communicate its heat to the next layer of mixtures and so ignite it. Thus by successive heatings of layers the flame would propagate "uniformly." The expansion of the burnt gas, however, if explosion takes place in a chamber confining the mixture, under the influence of the heat generated by the combustion, seems to start a pressure wave through the mass similar to a sound wave, and the flame cap can be seen to oscillate in its advance. This is said to be an "undulatory" movement, which is the second mode of propagation. If by any series of circumstances a number of waves of this kind should be set up in the mixture so that the crests of one wave matched the hollows of another, the waves would be eliminated. If, on the contrary, the crests of the first be superimposed on the crests of the second, third, etc., the waves would be synchronized and produce momentary high pressure, localized at the point representing the wave crest, thus giving rise to the third mode of propagation, the explosive wave. In any case a wave in the mass that may synchronize with waves of combustion will exaggerate the possibility of producing the explosive wave. Agitation of the mass, such as is produced by a jet impinging into

the main mass, will do this, and so will a wave of piston compression. This is a matter of very considerable importance in engines, for, if the exhaust chamber be not of the right form, there may be poekets or isolated masses of mixture so placed that ignition starting in one will raise the pressure in that, causing a flow of gases toward the other with a corresponding agitation and synchronizing of waves, resulting in the explosive wave. An explosive wave gives rise to pressures in this way very much in excess of the pressure due merely to the heat liberated, reaching 600 pounds per square inch in the engine cylinder. If the ignition be early; that is to say, if ignition be started while the piston is still compressing gas, there will invariably result similar explosive waves, straining the engine without any useful effect.

PRESSURE DUE TO EXPLOSION.

The pressure after exploding the charge will depend upon the amount of heat liberated and upon the weight of gas present. The amount of heat liberated by the explosion of the mixture of vapor and air will depend upon what fuel it is, whether kerosene, gasoline, or alcohol; the proportions of vapor to air; the amount of burnt gases left in the clearance, and the extent to which the charge has been heated on entering the cylinder during the suction stroke, and, finally, upon the compression pressure before ignition. It is easy to calculate this temperature rise on assumed values for these conditions, but it is just as easy to prove these assumptions wrong, so that computations of this kind are of no great value. Designers must, however, design an engine to resist these pressures, and so must have experimental values of this pressure. They are also valuable to experimenters in interpreting the performance of the engine by comparing the highest pressure observed in some case with the normal. If the normally high pressure is not attained, it has been due to an improper point of ignition, a loss in charge, or a weak mixture. The experimenter can also distinguish between normal pressure due to the heat liberated and abnormal ones due to explosive waves, which are destructive to the engine bearings and metal parts, but not useful for producing work.

LIQUID FUELS.

The liquid fuels available for use in exploding engines—that is to say, for vaporizing and mixing with air in a properly constructed mechanism—have quite different characteristics. With respect to their source they can be divided into two classes: The first, crude petroleum and its distillates, which have some characteristics in common; and the second, alcohol, which is quite different from any of the petroleum distillates in all of its characteristics. When crude oil is boiled or refined, vapors are evolved which may be condensed. These

condensed vapors are called "distillates." In a refinery the temperature of the vapor coming off is measured and the distillates collected either between two limits of temperature or two densities, for as the boiling proceeds the temperature of the liquid and vapor continually rises and the density of the distillates also continuously rises. The first distillates are light and the last heavy. The last distillates constitute lubricating oils; the first and intermediate distillates constitute gasoline, naphthas, kerosene, etc., available for revaporation for use in exploding engines. These distillates are not simple fuels, but are mixtures of different chemical composition, always containing carbon and hydrogen. They comprise all the material that goes over in the boiling between two limiting densities, the mixture having a sort of average density.

There is not a good agreement between the character of the materials designated gasoline, kerosene, etc., and the temperature of distillation and densities employed in different places, so that such names seem to have more commercial significance than scientific value. The following table shows one set of values that is probably as good as any densities reported, they being compared with water and given in Baume's hydrometer scale at 59° F.:

Definition of petroleum distillates.

Name.	Boiling point. ° F.	Specific gravity.	Density. ° Baume
Petroleum ether.....	104-158	0.650-0.660	85-80
Gasoline.....	158-176	.660- .670	80-78
Naphtha C.....	176-212	.670- .707	78-68
Naphtha B.....	212-248	.707- .722	68-64
Naphtha A.....	248-302	.722- .737	64-60
Kerosene.....	302-572	.758- .864	56-32
Lubricating oil.....	572 up	.864- .960	32-15

Gasoline is far different from a simple substance which would have a fixed boiling point, and therefore theoretical calculations on the heat of combustion, air necessary, and conditions for vaporizing or carbureting air are of little value. On the other hand, alcohol is a simple substance, or, more properly, there are many alcohols each of which is a simple substance; but they are not so used in an engine. The alcohol which it is proposed to manufacture for industrial uses under the recent law is ethyl alcohol having a definite chemical composition C_2H_5OH . This material is seldom, if ever, obtained pure, it being generally diluted with water and containing other alcohols when used for engines. The alcohol present is in an impure condition. Thus 90 per cent alcohol means alcohol and water mixed so that there is 90 per cent of alcohol by volume present. The density of the alcohol depends upon the amount of water present, of course, and upon the temperature as well, as it varies considerably

with temperature. The Smithsonian tables of the density of alcohol with temperature are given below in part with a computation by which the percentage of alcohol by weight or volume can be determined when the density and temperature of the mixture are known:

Smithsonian table of specific gravities of ethyl alcohol.

Specific gravity at 60° F. compared with water at 60° F.	Percentage of alcohol—		Specific gravity at 60° F. compared with water at 60° F.	Percentage of alcohol—	
	By weight.	By volume.		By weight.	By volume.
0.834	85.8	90.0	0.822	90.4	93.4
.833	86.2	90.3	.821	90.8	93.7
.832	86.6	90.6	.820	91.1	94.0
.831	87.0	90.9	.819	91.5	94.2
.830	87.4	91.2	.818	91.9	94.5
.829	87.7	91.5	.817	92.2	94.8
.828	88.1	91.8	.816	92.6	95.0
.827	88.5	92.1	.815	93.0	95.3
.826	88.9	92.3	.814	93.3	95.5
.825	89.3	92.6	.813	93.7	95.8
.824	89.6	92.9	.812	94.0	96.0
.823	90.0	93.2			

For the range of percentage contained in the above table, the correction for temperatures different from 60° F. should be made as follows:

If the density is measured at a temperature above 60°, 0.0005 should be added to the measured density for each degree which the temperature at the time of the measurement differs from 60°. When the temperature at the time of measurement is below 60°, the same correction should be subtracted from the measured density. The corrected density should then be used in the table for finding the true percentage of alcohol.

The percentage of alcohol found in a sample is always likely to be greater when determined chemically than when determined by the hydrometer, because the presence of impurities in the way of solids dissolved in the alcohol or as any of the series of higher alcohols tends to make the specific gravity of the sample greater, and hence make it indicate too low a percentage of alcohol.

Although pure alcohol is, as was shown above, a simple chemical substance, and so permits of computations on the heat of combustion, the amount of air necessary for its proper combustion, the amount of heat to vaporize it, the proper air temperature for carburetion, or anything else that might be desired in connection with its performance in an engine, yet in actual engines this pure alcohol is never used. The revenue laws permit the tax-free use of only denatured alcohol, that is to say, a fuel consisting principally of ethyl alcohol, but with various substances added to it to render it unfit for drinking, and which may have little or much effect upon its value as an engine fuel. In the United States the substances to be added are at least 10 parts

of methyl alcohol to 100 parts of 90 per cent ethyl alcohol by volume, in addition to one-half of 1 part benzine. Even this small addition makes it difficult, if not impossible, to make accurate calculations concerning what the mixed fuel will do in an engine. In Europe, during all these years of development, many hundreds of tests have been made with all sorts and conditions of fuel mixtures, some of them with alcohol which is free of denaturants, some with denatured alcohol, and some with purely experimental mixtures. Every different fuel element and every different fuel mixture will have characteristics when used in an engine, so that in comparing these engine results it is clearly necessary to have some knowledge of the nature of the fuel mixtures used.

HEAT OF COMBUSTION.

One of the most important things to know concerning a fuel is the amount of heat it will liberate when burned, or its heat of combustion, for by this the weight of fuel burned per horsepower-hour can be transformed to thermal efficiency. This is determined practically by burning the fuel in a very accurate instrument called a calorimeter, so arranged that all of the heat will warm up water so that the amount of heat liberated may be determined by the temperature rise of this water. The heat of combustion, thus determined for the gasoline which we used in our tests, was found to be 21,100 B. T. U. per pound of gasoline. It is known that the heat of combustion of gasoline is not very different from that for the crude oil or any of the other distillates, and in common practice it is usual to take this value as 20,000 B. T. U. per pound of oil when other more accurate information is lacking. The alcohol which we used in our tests, 94 per cent by volume, had a heat of combustion as determined by the calorimeter of 11,900 B. T. U. per pound, which is just a little more than half that of the gasoline. The heat of combustion as determined by the calorimeter does not fairly represent the amount of heat set free in the engine cylinder, because when the fuel contains any hydrogen—and all of these fuels do—that hydrogen will form steam on combustion, which will condense to water and add its latent heat of condensation to the true heat of combustion. The heat of combustion obtained when the products are condensed, as in the calorimeter, is termed the high value; that obtained by subtracting from this high value the latent heat of condensation of such water as is formed is termed the low value. In reporting a calorific power for any of the oils or alcohol it must be clearly known whether the value is high or low, as they are appreciably different. Especially important is this when it is known that only the low value is set free in exploding

engines, because the exhaust gases are always hot enough to prevent condensation of steam. These fuels contain carbon and hydrogen in various proportions and the alcohol contains, in addition, some oxygen. Knowing the heat of combustion and the elements, it would seem possible to calculate the heat of combustion of compounds of these elements, and various formulas have been proposed for this purpose which are used in some cases by European experimenters in reporting their results. It is interesting to note in this connection that the heat of combustion determined by such a formula from its ultimate analysis seldom gives values that agree with the calorimeter. This is because of certain assumptions made on the molecular constitution of the elements shown to be present. Thus, when hydrogen and oxygen are present in water proportions it is assumed that the group can not give any further heat of combustion, and further, that there is no heat absorbed to separate the group from the other molecules as heat of dissociation. This assumption vitiates the results, but for any given fuel a constant can be determined in the nature of a correction to the calculation to make the results agree with the calorimeter, which it is possible to apply with fair accuracy to similar fuels.

AIR NECESSARY FOR COMBUSTION.

When a fuel has a definite chemical composition, the air necessary for combustion can be exactly determined; otherwise it must be an assumption. This calculation can be made, therefore, for ethyl alcohol or for methyl alcohol, but it is difficult, if not impossible, for a denatured alcohol or for gasoline or kerosene.

In an actual engine the amount of air is proportioned to the amount of vapor, not by any exact measurement of either, but by experimental trial, to secure either the best results in maximum power or minimum fuel consumption, but in this case the experimenter has no knowledge of the fuel supplied but unburned. As a check upon this adjustment, it has been the practice in the European tests, especially those of Sorel, to analyze the exhaust gases with a view to determining the amount of air supplied by the chemical composition of the exhaust. An engineer operating the engine, however, has no means for determining results such as this, and, in fact, cares very little just what quantity of air is being supplied so long as it is clear that no fuel is passing away unburned or so long as the engine is doing the proper amount of work with the minimum of fuel.

VAPORIZATION OF FUEL.

Before any liquid fuel is available for use in an exploding engine it must be vaporized, and this vapor must be mixed with air in the proper proportions—that is, as near the chemical proportions as may be possible. Thus the preparation of the fuel for use in an exploding engine involves three steps. First, vaporization; second, mixing with air; third, adjustment of proportions. The devices used in the engines to accomplish these things show the widest variation of detail design. In some of these devices the fuel is boiled in a chamber which is then known as a vaporizer, and the vapor is allowed to flow into a stream of air entering the engine, the amount of vapor being regulated by a valve, just as is done in a gas engine. During the process of vaporization the air is not in contact with the vapor as it forms. In the next type of vaporizer the fuel is dropped on a hot plate, over which the air flows on its way to the engine, and the proportions are fixed by the rate of air flow or by the rate at which the fuel is supplied to the hot plate or by the temperature of the plate. When the fuel will vaporize at a low temperature below that of atmospheric air, it is not necessary to have any heated plate, and the fuel may be dropped directly into the entering stream of air, the proportions being adjusted by the opening of a small valve. Kerosene requires a plate or chamber quite considerably heated to completely vaporize it, as the boiling point is high. Gasoline requires nothing of this sort, as it easily vaporizes at atmospheric temperatures. Alcohol lies between these two fuels in this respect. It requires temperatures higher than the usual atmospheric temperatures, but not so high as those necessary for kerosene.

A device for preparing the mixtures in these engines, which performs three functions—vaporizing, mixing, and proportioning—is called a carbureter. Carbureters are universally used for gasoline and similar easily vaporized substances. Vaporizers in one form or another are almost universally used for kerosene, although some kerosene carbureters have been devised differing from the gasoline carbureter chiefly by the addition of a heating part. Alcohol is used in both of these devices—that is to say, alcohol carbureters are common and so are alcohol vaporizers, but the carbureters more common than the vaporizers. An alcohol carbureter may differ not at all from a gasoline carbureter, but by reason of the high temperature of vaporization of the alcohol some method of heating either the air or the mixture is necessary to insure complete vaporization, and the more water present the higher the necessary temperature. In order that the above distinction may be clear and variations in the detail design for accomplishing the same purpose may be set forth, descriptions of a few typical devices are given.

One common form of pure vaporizer in use in the West is a retort, of the class involving the dropping of oil on a hot plate. This is shown in figures 5 and 6. The exhaust from the main engine enters the retort at the port (A). The hot exhaust gases heat a central drum, around which the generating wheel revolves. The generating wheel (C) is a hollow wheel or drum, containing channels or buckets on the periphery. This wheel is driven by a belt from the main engine around a driving pulley (fig. 6, G), transmitting power through a worm and gear to the driving spindle (I). The driving spindle is attached to the generating wheel, which revolves about one-half turn a minute. The heat radiating from the heated drum is intercepted by the generating wheel and utilized in transforming the oil

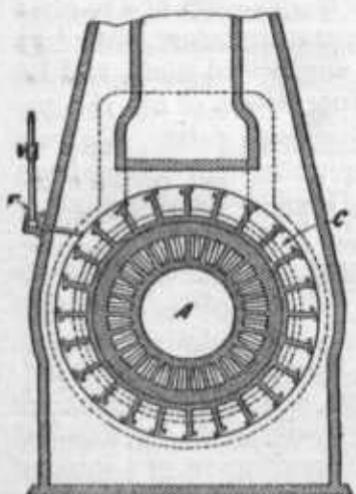


FIG. 5.—Section of retort vaporizer.

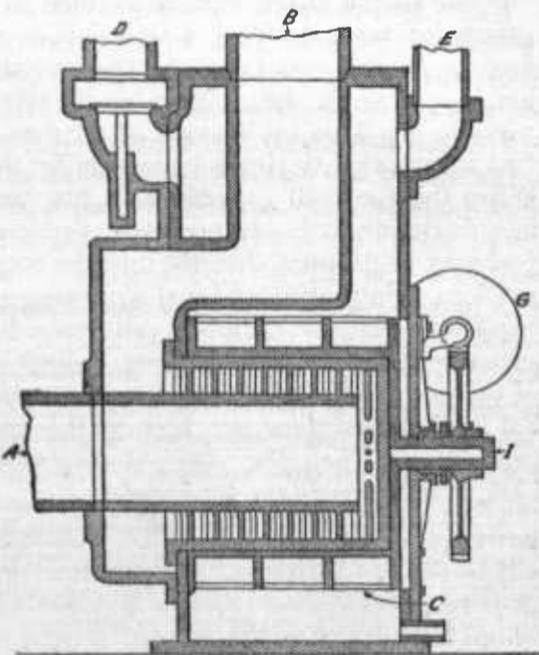


FIG. 6.—Section of retort vaporizer.

into gas as it is fed into the channels of the generating wheel through the oil port (fig. 5, F). As the oil is fed into the channels through the oil port it is carried up and over the top of the wheel, giving up its volatile parts by reason of the heat received from the wheel. The nonvolatile portion of the oil, or the residuum, remains in the channels until they reach the bottom, where the residuum drops into a reservoir and is automatically drained off through the residue port by means of a pipe with a drop of 8 inches or more below the retort, having a horizontal check valve on the end. The check valve is for the purpose of keeping the residuum from being drawn into the engine cylinder. The exhaust gases are carried away from the retort

by means of a pipe screwed into the flange attached to the exhaust outlet (fig. 6, B). As the gas arises from the wheel to the gas chamber it circulates around a hot exhaust pipe, thus being superheated. It is immediately drawn into the main engine cylinder by the suction of the engine, through a connection of pipe and fittings from the gas port (fig. 6, D), to the inlet to the engine cylinder, where it is ignited by whatever means may be used for that purpose. Air is also drawn by the engine suction into and through the retort ease, entering at the air-inlet port (fig. 6, E). In some cases the air-inlet pipe, connected to this port, runs about 2 feet and then turns down again. This is recommended to prevent gas from escaping through the air inlet between suctions.

There are no devices on the American market of the kind that specifically boils the fuel in a separate chamber. A device of this kind would have certain advantages over that of the simple hot-plate type for the following reasons: If the plate on which the oil is dropped gets too hot, the fuel will decompose, in addition to vaporizing, and leave on the plate a black sooty residue. This is because these fuels are very sensitive to decomposing from overheating. If the plates are not hot enough, the fuel will be only partly vaporized, and good fuel will be thrown away as residue. When the heating is to be accomplished by the exhaust gases, not only must a lamp be supplied for initial heating, which takes a long time with such a mixing device as this, but further, and more important, the temperature of the vaporizing plates is very difficult if not impossible to regulate. On fluctuating load, therefore, where the engine requires more or less vapor from time to time the hot-plate vaporizer would sometimes be decomposing fuel from excess heat, at other times only partly vaporizing it, and in any case proportions of air to vapor will be sure to be irregular, so that in the mixture there will sometimes be an excess of vapor and sometimes an excess of air. Such a hot-plate vaporizer, therefore, is adapted only to those oils that can not be otherwise treated in carbureters. For this reason retorts of this kind are almost solely confined to engines which use the crude oils.

There is on the American market a class of engines having a vaporizer which forms part of the cylinder head and which is heated by the explosions taking place inside the exploding chamber. Otherwise stated these vaporizers are themselves exploding chambers. One of these is shown in figure 7. On this figure, A is the vaporizer proper. Under it is seen a lamp (B) with a burner (C), and, to prevent undue radiation in heating, the burner and vaporizer are surrounded by a casing (D). This vaporizer is bolted to the cylinder head (E) and contains on its inner end a lip projecting

into the exploding chamber. A little pump injects a small stream of oil at every stroke and drops it on this lip from the pipe (F). This lip is very hot from previous explosions and from the lamp, which, by the way, is turned off when the engine begins work. The compression stroke of the piston forces the air in the cylinder over the lip and through the neck into the vaporizer bulb, thus mixing more or less completely the vapor which formed on the lip with the air that is forced over the lip into the bulb. Such hot-bulb vaporizers as this will work with practically all of the fuels—crude oils, gasoline, kerosene, and alcohol—with proper adjustments of the pump and of the temperature of the bulb. These bulbs perform another duty besides vaporizing and mixing. Their high temperature, that

of a red heat when in operation, is sufficient to ignite the mixture when the compression is high enough, thus eliminating any necessity for electric igniters. In engines fitted with this type of vaporizer no mixture enters the cylinder at all; nothing but air passes through the inlet valve. Oil is pumped in, drops on the vaporizer, there meets the air, with which a more or less complete mixture is formed, the mixture is compressed, and by the compression heated and ignited. This type of vaporizer igniter has, besides the above advantages, certain disadvantages: (1) The vapor is but imperfectly mixed in the air; (2) the exceedingly high temperature in the vaporizer, which it is impossible to avoid, will more than vaporize some

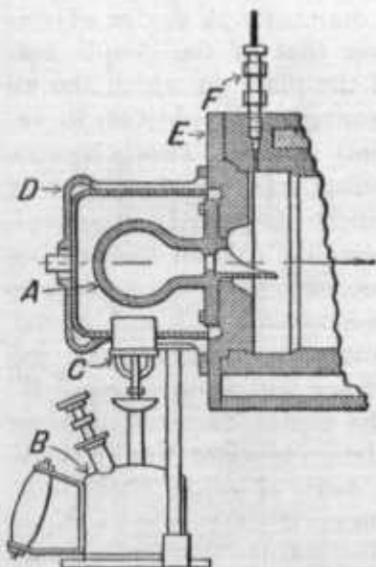


FIG. 7.—Section of hot-bulb vaporizer.

of the fuel, decomposing it and depositing soot if the fuel be hydrocarbon; and (3) another bad feature in the use of such a vaporizer is to be found in the fact that some air remains between the piston head and the bulb, and this is inactive, no fuel being burnt, the only active part being that which enters the bulb. Engines fitted with vaporizers of this kind, therefore, can not do as much work for the same size cylinder as an engine in which the entire mass of gases in the clearance is active explosive mixture. Furthermore, these engines will always use more fuel than is necessary because of the incomplete mixing of fuel vapor and air and the partial decomposition of some of the fuel.

Another vaporizer of the hot-plate sort, intended particularly for

alcohol, illustrated in figure 8, is known as the Brouhot, a French type. Exhaust gas enters at the bottom, as shown by the arrow and lettering on the ent, and rises through the iron chamber, which is corrugated to increase the surface without making the apparatus too bulky. Alcohol is admitted near the bottom of these ribs or corrugations and flows upward on the side opposite to that heated by the exhaust gases. The regulating valve is attached to permit some exhaust gases to pass around the heating chamber and so vary its temperature, but the regulation of temperature must be done by hand. Vapor rising from the surface of the alcohol in the top of the chamber meets air, which passes first through the regulating valve intended for the adjustment of proportions. The corrugations are such as to form a screw thread or a helix passage and the exhaust entering first at the bottom passes directly to the top of the chamber and downward in the helical groove to the bottom, so that the top of the helix will be the hottest part. Alcohol enters the bottom of the opposite helix, flows upward and vaporizes somewhere in its upward course, discharging into the air current at the hot top of the helix as superheated alcohol vapor. This vaporizer is, therefore, of the boiling type, but the boiling takes place on the surface of the liquid which is at the pressure in the suction pipe, and the rate of boiling is regulated by hand by admitting more or less exhaust gases to the vaporizing helix.

Separate vaporizers as distinguished from carbureters are essential for kerosene and common for alcohol. They have been described at this point because the principles of their operation are simpler than those of carbureters and they are less numerous and less representative.

Carburetion is a process distinctly different from boiling. Air may take up the vapor of a liquid just as it takes up the vapor of water, even when the temperature of the liquid or the temperature of the air is very considerably less than the boiling point of the liquid. In short, air may take up some vapor at any temperature whatever, and it is not necessary that the liquid be brought to the boiling point. The amount of vapor which air can take up by simply coming in contact with the liquid depends upon the vapor tension of the liquid and the pressure of the air. The air may be assumed to be always at

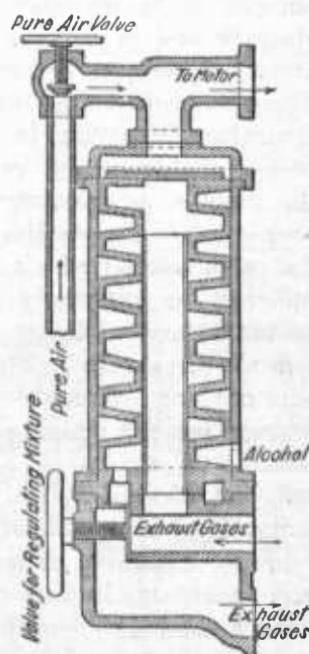


FIG. 8.—Section of Brouhot vaporizer.

atmospheric pressure, for the pressure in the suction pipe of an engine is but little less than that of the atmosphere. The amount of vapor that can be taken up from the liquid surface can be calculated quite exactly if the air is left in contact with the liquid long enough and if the liquid is a simple substance having a definite chemical composition and a definite vapor tension. The method is exactly the same as that used to compute the humidity of the atmosphere. Since gasoline is not a simple substance, such a calculation is impossible, but it is known by the practical operation of engines having carburetors that at ordinary atmospheric temperatures the air is quite hot enough to vaporize enough gasoline to make a proper explosive mixture and is in fact capable of absorbing quite a considerable excess of gasoline before it becomes saturated with gasoline vapor. There is, however, no difficulty whatever from the standpoint of air saturation in giving to the air sufficient gasoline vapor to make a proper explosive mixture for engines if the air be left in contact with the gasoline long enough, or if, in addition, the contact be of the proper sort. As gasoline consists of substances of different volatility, the mere contact of air with the surface of the liquid may not be sufficient to uniformly vaporize the mixture. The more volatile parts may come off first and there may be a residue which it will be difficult to vaporize. This difficulty was met with in the earlier carburetors and overcome in a way that will be explained presently. Alcohol being a simple substance, with a definite vapor tension, it is possible to calculate at what temperature dry air must be to contain sufficient alcohol vapor. If the air have any temperature higher than this, it is capable of carrying more alcohol than is necessary for a proper explosive mixture or capable of absorbing the amount of vapor necessary in a shorter time.

By a somewhat lengthy calculation it may be shown that dry air at a temperature of 72° F., when saturated with alcohol vapor, has just enough of the vapor to form the theoretically best mixture for perfect combustion. If the air be moist, or the alcohol contain water, or the time allowed for vaporization be too brief, the temperature of the air must be higher than 72° F. to form a proper explosive mixture.

As the engine does not use pure alcohol of this sort, but rather mixtures known under the general name of denatured alcohol, the corresponding temperature necessary to secure this proper vaporization will be different from that just given, but just how different can not be stated. However, it is certain that air at any temperature will take up some vapor of alcohol and that the higher the temperature of the air the quicker it will take up the necessary amount for the best explosive mixture. In the case of incomplete vaporization some of the fuel may be carried along as spray, which may be vaporized in

the cylinder on the compression stroke or may not, but if not then it certainly will be after the explosion of the rest. It would seem desirable, therefore, to quite considerably heat the air supplied to an alcohol carburetor; yet indefinite heating of the air will bring about a bad effect on the engine, because it will make the charge hotter at the end of compression, or, in other words, decrease the weight of the charge in the cylinder. The horsepower of the engine, other things being equal, will be decreased in direct proportion as the density of the charge is lowered by this heating, so that, on the one hand, heating of the air is good for complete vaporization, but bad, if carried to excess, in reduction of power.

The earliest forms of carburetors operated on the principle of simple contact between the gasoline and air. One of the most suc-

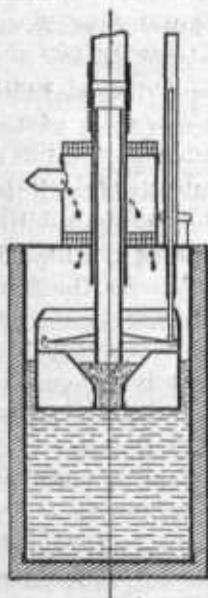


FIG. 9.—Section of Daimler carburetor.

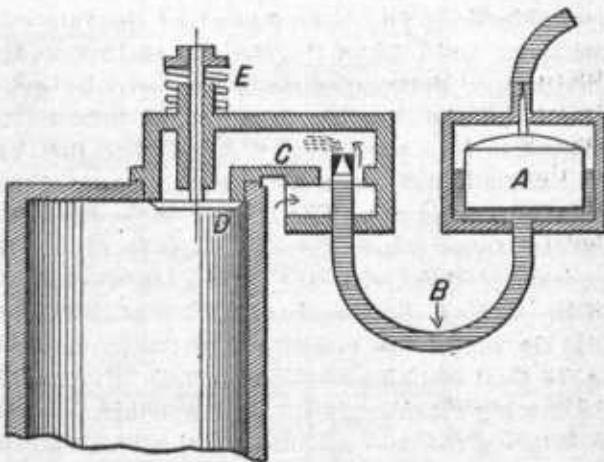


FIG. 10.—Section of Maybach carbureter.

cessful of this type is that used by Gottlieb Daimler, to whom all credit should be given for the developing of this type of carburetor and by it the high-speed liquid-fuel engine. Daimler's surface-contact carburetor is shown in figure 9. It consists of a tank fitted with a central tube and float. In the bottom of the tank is the gasoline, on its surface the float, and in the float a hole through which the gasoline may rise to a certain height. Air flows down a central pipe and strikes the surface of the gasoline at the top of the hole in the float, picking up vapor, the mixture flowing directly to the engine. The pipe down which the air flows is kept by the float to a constant amount of submersion, so that the air must bubble through the gasoline to a certain depth. The chief objections to this carburetor

reter are found to be: (1) It would vaporize the most volatile part of the gasoline and leave the residue, which is difficult to vaporize; (2) the slower the flow of air through the carbureter the more vapor it takes up, so that at small engine loads or slow speeds the mixtures were likely to be too rich if the adjustments were made for high speeds of the engine or rapid flow, and (3) the vaporization of the gasoline from the surface of the liquid cooled the liquid, because the latent heat of vaporization was largely absorbed from the liquid and the vaporization was slower as the liquid grew colder. In general this carbureter was incapable of maintaining a constant proportion of gasoline vapor to air at all rates of flow or at various temperatures of either air or gasoline and incapable of vaporizing all of the complex gasoline.

The first important improvement on this carbureter was made by Maybach, an engineer in the Daimler Works. This is shown diagrammatically in figure 10. Maybach's carbureter was designed primarily to make the apparatus independent of air temperature within a certain limit and independent of the rate of flow—that is to say, the speed and load of the engine—and likewise to prevent fractional distillation. The gasoline is delivered by gravity or pressure into the top of the chamber at the right through the opening, which is controlled by a needle valve attached to the float (A). As the float falls more liquid is admitted, which causes the float to rise, again decreasing the supply. The bottom of the float chamber is connected to the carbureter proper through the pipe (B). The air enters upon the aspirating stroke when the valve (D) is opened, whereby the pressure in the mixing chamber is made less than that of the atmosphere, so that the liquid fuel rises through the jet orifice by excess of pressure in the float chamber over the suction pipe and mixes with the air in the mixing chamber (C). It will be apparent that no valve is necessary except the one controlled by the float, and the fuel will only enter the mixing chamber (C) as required with the pressure variation on the suction stroke of the motor. The theory on which this type of carbureter was intended to maintain proportions was found in practice to be not quite true, although nearly enough so to make it a great advance. It was expected that by reason of the partial vacuum in the air pipe surrounding the gasoline jet, due to the engine suction, it would lift from the jet a quantity of the gasoline proportional to the quantity of air. In other words, assuming a vacuum in the suction pipe, the quantity of gasoline that would flow from the constant-level chamber, under the influence of the vacuum, would increase in the same proportions as the quantity of air flowing from the atmosphere to the same vacuum. It was found that as the vacuum increased, owing to the speed of the engine and the load, more fuel passed over than was wanted, assuming that the carbureter was prop-

erly set for small rates of flow. This led to the introduction of another valve opening to the atmosphere between the carbureter proper and the suction valve of the engine. To facilitate adjustment of the vacuum another valve is inserted into the air pipe, entering the carbureter, and to facilitate initial adjustment of the mixture a sharp-pointed valve called a "needle valve" was inserted over the gasoline jet or nozzle. The arrangement of such a carbureter as this is shown in figure 11. The maintaining of a constant level just beneath the gasoline nozzle was found to be rather difficult if the float stuck or the float valve leaked. For this reason diaphragms have been tried as a substitute, but their use is still experimental. The carbureter is otherwise the same essentially as described above.

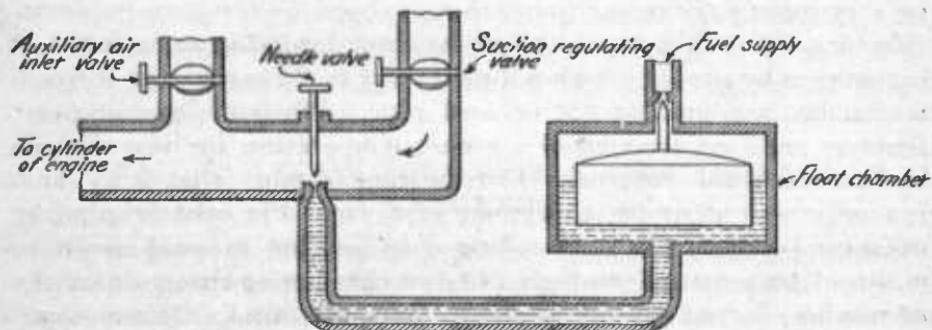


FIG. 11.—Diagrammatic section of constant-level carbureter, with needle-valve adjustment.

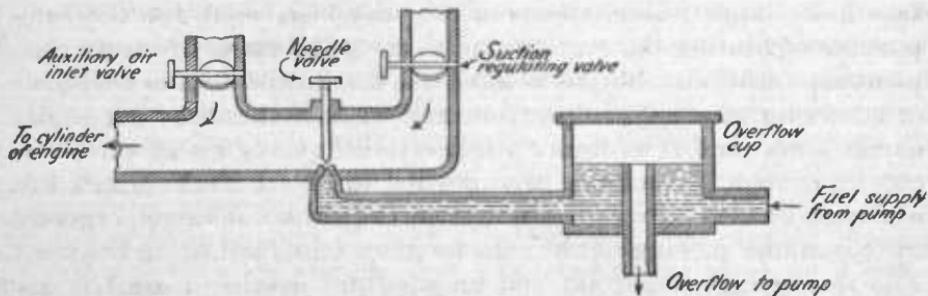


FIG. 12.—Diagrammatic section of constant-level carbureter, with overflow cup.

When the engine to be used is not in boats or automobiles, subject to shocks and oscillations, but is at rest, the third arrangement (fig. 12) can be employed to keep the fuel level constant in the nozzle and to prevent flooding of the carbureter. A small chamber is fed by a pump attached to the engine and working with it. Gasoline is supplied much in excess of what the engine will burn, and the excess is allowed to run back to the tank through an overflow pipe. This overflow pipe fixes the level of the gasoline in the spray nozzle.

This arrangement is selected as a desirable one because it is effective and because the fire underwriters' rules require that the gasoline tank be placed below the level of the engine to minimize danger by fire. In some of the latest types of carbureters the valve between the

carbureter proper and the suction, which is intended to open at high speeds, is made automatic and opens by a spring. This has given rise to the name "automatic carbureter." In order to more intimately mix the spray with the air, various devices have been introduced above the spray, such as cones, plain and corrugated, pieces of wire gauze at rest and spinning around under the influence of a fan driven by the entering air. In technical language these devices are known as "pulverizers," but really are nothing more than means for breaking up the gasoline into fine drops to permit of a more intimate mixture with air. It was supposed that the air would have sufficiently high temperature to absorb all the vapor that would be generated by the spray which was drawn into it, but in very cold weather or on very moist days it was found that at times the results were unsatisfactory. For this reason the air has been heated in some forms of carbureters by simply drawing it on its way to the carbureter through a chamber surrounding the exhaust pipe. When the gasoline carbureters are used for alcohol a higher temperature for vaporization and carburetion is required. This heating becomes a necessity, and, not only is it desirable to extract heat from the exhaust pipe by drawing air from the surrounding chamber, but in some cases the mixture also is passed through a heated chamber so that no particles of residue can remain unvaporized. In some forms of French carbureters the heat of the jacket water, which if it flows not too fast has a high enough temperature, has been used for the same purpose of heating the air, the liquid, or the mixture, to insure complete vaporization. But, as pointed out before, the alcohol will more or less vaporize at any temperature, and we have shown by our engine experiments that at ordinary temperatures, averaging about 60° to 80° F., enough alcohol can be vaporized to give a working mixture, although we also have evidence that all the alcohol does not vaporize, the remainder passing out as exhaust gases unburned or decomposed. The variation in important and unimportant details of construction in these carbureters intended either for kerosene, gasoline, or alcohol is almost beyond belief. Practically everybody who has ever had anything to do with these engines has designed a carbureter, and yet it can be proved beyond question that no carbureter on the market to-day, be it intended for any of the fuels named, is capable of carrying out that for which it was designed. While some vaporizers and carbureters to some extent will maintain the mixture perfectly well for some rate of flow or some particular temperature, no carbureter that has ever come to our attention will maintain an absolutely correct mixture for high speed and low speed, cold or hot air, moist or dry air, or changes in the rate of supply or engine load that must be met with in practical engine operation.

EFFECT OF INITIAL COMPRESSION.

By rather involved mathematical calculation it may be shown that the theoretical efficiency of an internal-combustion engine depends upon the amount of compression given to the combustible mixture during the compression stroke of the piston. The greater the compression the higher should be the efficiency. In practice it is found that various causes operate to diminish the efficiency, thus tending to offset the benefits of high compression. Still, with good mechanism it is found that an increase of compression up to a considerable amount improves the efficiency.

With gasoline the compression can not be carried much above 80 pounds per square inch without danger of premature explosion of the fuel charge in the cylinder. With alcohol the compression may be safely increased to 200 pounds per square inch if desired if the engine is well cooled, and in numerous European engines 150 pounds have been regularly used.

PRACTICAL EXPERIENCE WITH ALCOHOL ENGINES IN GERMANY.

There is one report available on the comparative value in unskilled hands doing commercial work of alcohol engines compared with the machines they have displaced, both with respect to fuel consumption and cost and the care and expense necessary for maintenance. Professor Streeker, of Leipzig, sent a circular letter to 120 farmers in Germany who were using alcohol engines, which had displaced steam engines for farm purposes. There were 120 of these engines, of three different makes and ranging in size from 6 to 25 horsepower.

These engines were working more or less throughout the year, the maximum number of hours being 2,500 per year, the minimum 324, and the average 996. The first question addressed to the farmers concerned the amount of work these engines were capable of doing compared with the engines they displaced at the same rated horsepower; 46 per cent thought them equal, 47 per cent thought them superior, and only 4 per cent considered them inferior, but qualified this by stating that the steam engine must be fired with greater regularity. The next question concerned the expense for fuel. The average amount of coal used in a steam engine was 4.28 kilograms per metric horsepower hour, equivalent to 9.55 pounds per brake horsepower hour, with an addition of 100 pounds per day for starting. The price of coal averaged 20.7 marks, which is equivalent to \$4.47 per ton. The fuel used in the alcohol engine was not all the same. Nineteen per cent used German denatured alcohol; 81 per cent used a mixture containing 20 per cent benzole, and the consumption varied from 1.1 liters per German horsepower hour (2.35 pints per brake horsepower hour) maximum to 0.43 liter per German horsepower hour (0.92 pint per brake horsepower hour) minimum, the average

being 0.57 liter per German horsepower hour (1.22 pints per brake horsepower hour).

Denatured alcohol cost at that time in Germany 17 marks per hectoliter (15.2 cents per gallon) and benzole costs 21.5 marks per hectoliter, equivalent to 19.4 cents per gallon. The 20 per cent benzole mixture therefore costs 17.9 marks per hectoliter (16.11 cents per gallon). Gasoline was almost invariably used for starting, and 85 liters (22.4 gallons) seems to be the average amount necessary per year, costing 36 marks per hectoliter (32.4 cents per gallon), with a total cost for starting of about 30 marks (\$7.25) per year. The fuel consumption averaged 4.28 kilometers of coal per horsepower-hour (9.41 pounds) and 0.57 liter (1.2 pints per horsepower-hour) for alcohol. This is rather higher than reported in the various tests on these engines, but these figures represent the average of 74 engines, considering only those of 10 horsepower, and assuming that the large sizes balance the smaller sizes. With these figures a steam engine with an average of 10 horsepower operating 1,000 hours per year will cost \$240 per year for fuel. The alcohol engine, operating the same number of hours at the price given, would cost \$253 per year for fuel. This makes it appear that the cost of operation of the alcohol engine is greater than the steam engine in spite of superiority of the alcohol engine compared with steam. It is next pointed out that the transportation of alcohol in tanks and barrels is cheaper than that of coal (loose), and the convenience in handling and the elimination of a man constantly attending the fire, such as was found necessary with steam engines, really gives the alcohol engine a small advantage on operating cost. It was also shown that the cost of lubricants is no greater for the alcohol engine than for the steam engine, while the cost of repairs seems to be less. Of the 120 farmers, 9 per cent found the alcohol engine to cost more to maintain, 34 per cent found no difference, and 57 per cent found the maintenance less for the alcohol engine. Another interesting thing brought out by the inquiry was that the alcohol engine was capable of operating in all kinds of weather, in some cases with the temperature at 18° F. below freezing, only a little more time being required to start up. It was found also that there was absolutely no difficulty in instructing the ordinary person in the proper methods of handling and operating these engines.

The number of engines in use in Europe seems to be quite large, although definite information on this is difficult to obtain at the present time. One estimate, on fairly good authority, places the figure between 5,000 and 6,000 in Germany. The number that will probably be used in this country is difficult to estimate, but the large number of builders now engaged in turning out gas and gasoline engines—one firm alone being equipped to turn out 425 per day—seems to indicate that, if the cost of alcohol fuel compared with gasoline and coal be not too great a handicap, there is a probability of an exceedingly large industrial development in this field, though not immediately.

Besides the cost of alcohol per horsepower-hour compared with gasoline, there is another element that must be favorable before the introduction of the alcohol engine can become very wide, and that is the interest of the builders. From correspondence with the builders of gasoline and kerosene engines in this country, it appears that practically all of them are indifferent to the introduction of alcohol machines. They are quite willing that their regular engines be sold for and used with alcohol, but they are not inclined to give any guarantees on performance. Individually they are decidedly averse in nearly every case to undertaking the development of a special alcohol engine, because this means extra expense in drawings, patterns, gigs, tools, etc., and it is certain that they will do very little so long as the public will continue to buy gasoline and kerosene engines and not insist upon having a specially designed alcohol machine.

CONCLUSIONS.

The following conclusions regarding the use of alcohol as fuel for engines as compared with gasoline are based on the preliminary results of the Department's experiments, upon results of the European experiments and investigations which have been presented in the foregoing pages, and upon the general knowledge of the authors:

(1) Any engine on the American market to-day, operating with gasoline or kerosene, can operate with alcohol fuel without any structural change whatever with proper manipulation.

(2) Alcohol contains approximately 0.6 of the heating value of gasoline, by weight, and in the Department's experiments a small engine required 1.8 times as much alcohol as gasoline per horsepower hour. This corresponds very closely with the relative heating value of the fuels, indicating practically the same thermal efficiency with the two when vaporization is complete.

(3) In some cases carburetors designed for gasoline do not vaporize all the alcohol supplied, and in such cases the excess of alcohol consumed is greater than indicated above.

(4) The absolute excess of alcohol consumed over gasoline or kerosene will be reduced by such changes as will increase the thermal efficiency of the engine.

(5) The thermal efficiency of these engines can be improved when they are to be operated by alcohol, first by altering the construction of the carburetor to accomplish complete vaporization, and second, by increasing the compression very materially.

(6) An engine designed for gasoline or kerosene can, without any material alterations to adapt it to alcohol, give slightly more power (about 10 per cent) than when operated with gasoline or kerosene, but this increase is at the expense of greater consumption of fuel. By alterations designed to adapt the engine to new fuel this excess of power may be increased to about 20 per cent.

(7) Because of the increased output without corresponding increase

in size, alcohol engines should sell for less per horsepower than gasoline or kerosene engines of the same class.

(8) The different designs of gasoline or kerosene engines are not equally well adapted to the burning of alcohol, though all may burn it with a fair degree of success.

(9) Storage of alcohol and its use in engines is much less dangerous than that of gasoline, as well as being decidedly more pleasant.

(10) The exhaust from an alcohol engine is less likely to be offensive than the exhaust from a gasoline or kerosene engine, although there will be some odor, due to lubricating oil and imperfect combustion, if the engine is not skillfully operated.

(11) It requires no more skill to operate an alcohol engine than one intended for gasoline or kerosene.

(12) There is no reason to suppose that the cost of repairs and lubrication will be any greater for an alcohol engine than for one built for gasoline or kerosene.

(13) There seems to be no tendency for the interior of an alcohol engine to become sooty, as is the case with gasoline and kerosene.

(14) With proper manipulation, there seems to be no undue corrosion of the interior due to the use of alcohol.

(15) The fact that the exhaust from the alcohol engine is not as hot as that from gasoline and kerosene engines seems to indicate that there will be less danger from fire, less offense in a room traversed by the exhaust pipe, and less possibility of burning the lubricating oil. This latter point is also borne out by the fact that the exhaust shows less smokiness.

(16) In localities where there is a supply of cheap raw material for the manufacture of denatured alcohol, and which are at the same time remote from the source of supply of gasoline, alcohol may immediately compete with gasoline as a fuel for engines.

(17) If, as time goes on, kerosene and its distillates become scarcer and dearer by reason of exhaustion of natural deposits, the alcohol engine will become a stronger and stronger competitor, with a possibility that in time it may entirely supplant the kerosene and gasoline engines.

(18)* By reason of its greater safety and its adaptability to the work, alcohol should immediately supplant gasoline for use in boats.

(19) By reason of cleanliness in handling the fuel, increased safety in fuel storage, and less offensiveness in the exhaust, alcohol engines will, in part, displace gasoline engines for automobile work, but only when cost of fuel for operation is a subordinate consideration. In this field it is impossible to conveniently increase the compression because of starting difficulties, so that the efficiency can not be improved as conveniently as in other types of engines.

(20) In most localities it is unlikely that alcohol power will be cheaper or as cheap as gasoline power for some time to come.